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50. Internationales Wissenschaftliches Kolloquium
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M. Dovica/ M. Gorzás/ P. Kaťuch/ J. Kováč

Mechatronics Aspects of In-Pipe Micromachine Design

ABSTRACT

In this paper we describe design and modeling of the wired in-pipe micromachine which is able to self motion in pipe with inner diameter 35mm. Their utilization is oriented on detection of defects on inner pipe surface, repair of localized defects, monitoring and maintenance of pipes and last but not least their utilization is oriented on ability drawing new cables into old and already unused pipe systems.

INTRODUCTION

The mobile machines for motion in the thin pipes (less than 35mm) represent today suitable area of research. Their utilization is oriented on detection of defects on inner pipe surface, repair of localized defects, monitoring and maintenance of pipes and last but not least their utilization is oriented on ability drawing new cables into old and already unused pipe systems. [1], [2], [3]
Utilization of motion principles by means of classic wheel and crawling traction for design of in-pipe micromachine is dimensionally limited. In the view of this reason for positioning and motion are used bristles in form of flexible beams which are orientated under precise angle towards pipe surface and they use difference friction. At the micromachines realization are used actuators that are designed and manufactured with different approach because efficiency of energic fields which generating forces that are need for initiation of micromachine in motion decreases with dimensions.
In-pipe micromachine, that will be analyzed in next, is designed to motion in straight pipe with 35mm inner diameter in view of possibility its another extension by the monitoring system in form of CCD camera or surface defects sensor.

1. CONCEPT OF MICROMACHINE

Micromachine consists of the basic parts namely the DC-micromotor with concentric transmission (rear block), the worm gearing, crank mechanism, front block and the smart bristles (Fig.1).
Front row of the smart bristles is mounted on the front block which is located on the linear sliders. Rear row of the smart bristles is mounted on body of the micromachine. Front block is also connected with the worm gears by the crank mechanisms.

Motion principle is based on transformation of the rotary to the linear motion by the worm gearing and the crank mechanism. Change of the distance between front and rear row of the smart bristles is created by the linear motion of the front block whereby the sliders.
Motion of the micromachine insures difference friction between the smart bristles and the pipe surface at the forward and backward movement. [5]

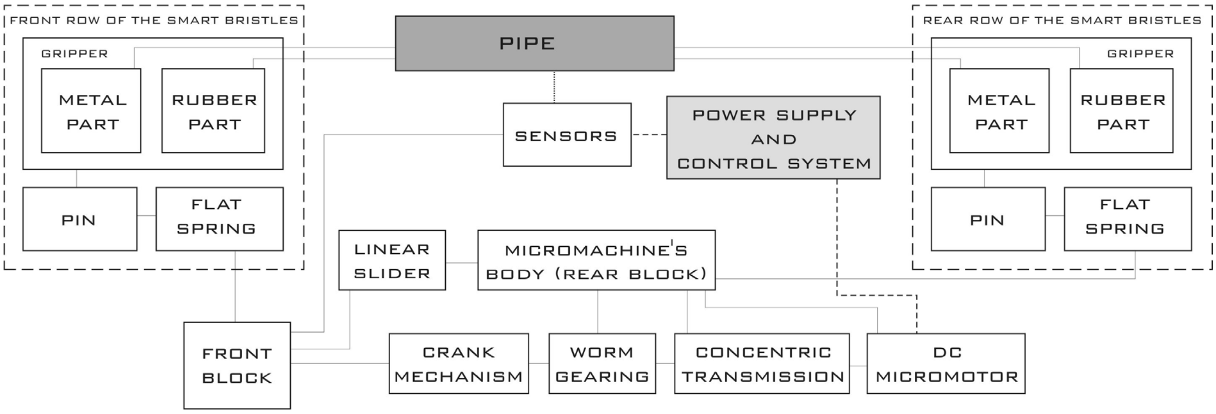

Fig.1 Block diagram of the in-pipe micromachine

At the fig.2 is shown the block diagram of the in-pipe micromachine control system. Control system design respects of the continuous movement requirements in case of loading conditions (there are micromachine mass change, geometrical parameters of pipe change etc.).

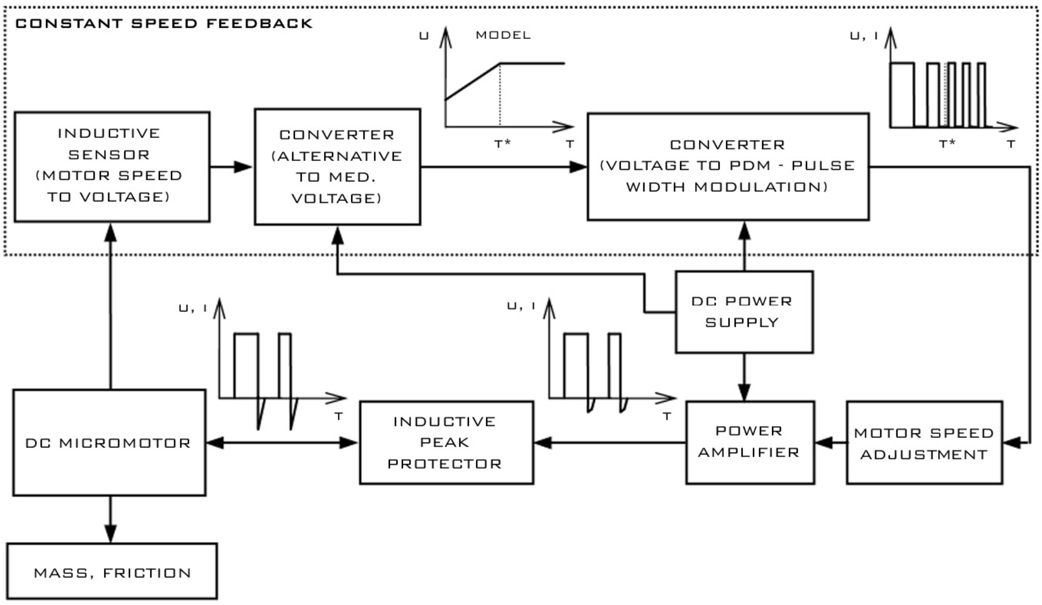

Fig.2 Block diagram of the in-pipe micromachine control system

Prototype based on design (Fig.3) was functionally tested and verified. From testing and verification result modification requirement in order to motion optimisation.

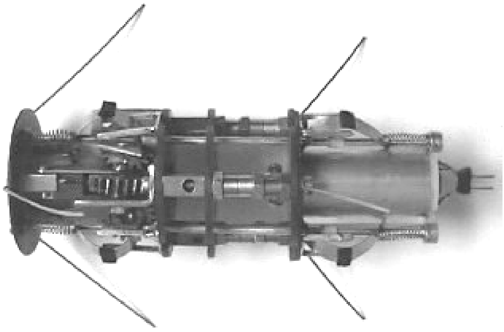

Fig.3 Prototype of the in-pipe micromachine

Motor was exchanged (with low energetic consumption motor). One transmission rate was added in order to torque extension and rotation speed reduction. Smart bristles were used and connected with modified connection place by reason of possibility to change the length of bristle by experiment and thereby extension of operating range from the point of view of pipe's diameter (Fig.4).

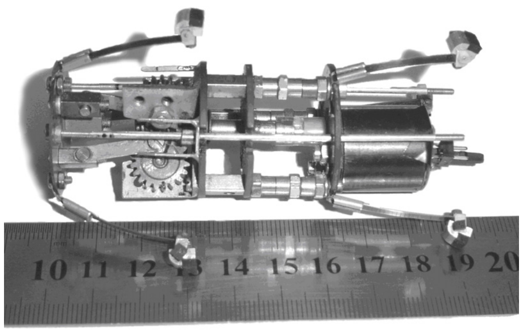

Fig.4 Modified prototype of the in-pipe micromachine

2. SMART BRISTLES

Bristles are utilizing as support element in in-pipe micromachine which are creating force connection between micromachine and pipe. They are applied on both modules (front and rear) which execute each other different motion eventually identical motion in different time. Due to difference friction increases in forward and backward motion new bristle concept was designed. Smart bristle (Fig.5) outgoing from reflection used two various materials which adhesion coefficient in combination with material of pipe surface is different. This material pair is combination metal-rubber. [4]

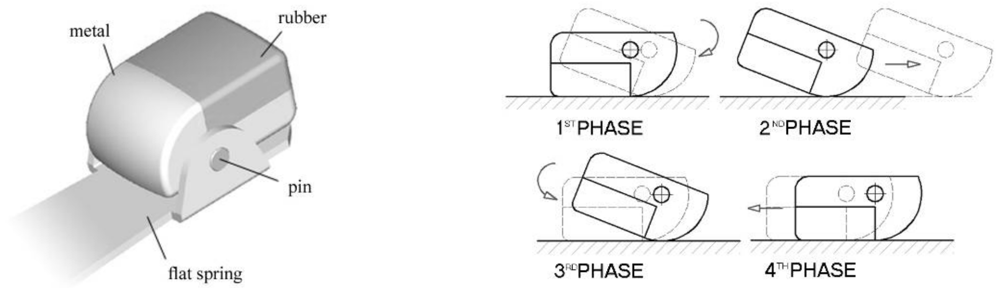

Fig.5 Design and motion of smart bristle

Forward motion: In 1st phase (Fig.5) occurs gripper rolling on pipe surface. In 2nd phase occurs gripper sliding on pipe surface. Friction of metal-metal material pair.
Backward motion: In 3rd phase (Fig.5) occurs gripper rolling on pipe surface. In 4th phase after what rubber plate contacts with pipe surface occurs expressive increase of friction force in tangent plane and thereby to contact elements lock-up. Friction of metal-rubber material pair.
Smart bristle function is verified on the prototype in-pipe micromachine (Fig.6).

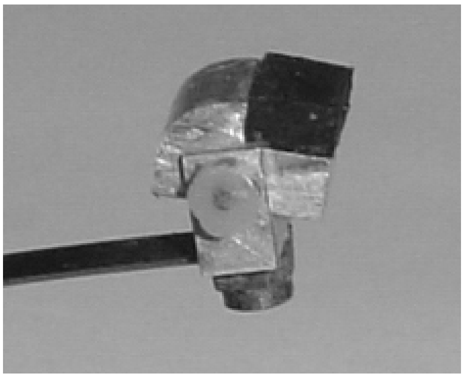
Fig.6 Prototype of smart bristle

For simulation requirements effects for selected parameters are defined

- for pipes made of steel, glass and other pipes with sufficient hardness is possible to ignore effect of rolling resistance,
- in quality machined contact surfaces between gripper and pin and using a suitable materials is possible to ignore a little effects of pin friction,
- if is not necessary the ideal simulation of real condition, example for optimization, is possible to ignore the effect of gravitational force, which is 1000 times smaller than size of bristle normal force.

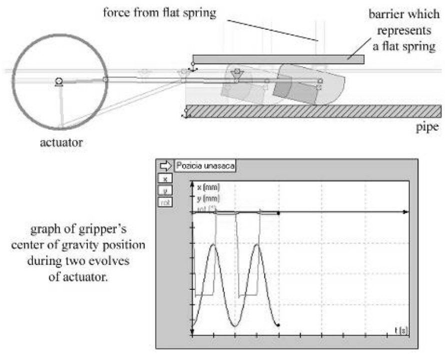

Fig. 7 MSC.Working Model 2D bristle model

The simple model confirm the function of smart bristles and he was made in MSC.Working Model 2D interface (Fig.7).This program makes possible to build a simply 2D models in which is possible to simulate dynamic actions. WM2D allowed understanding the principles of the movement, helped with analyzing the effect of compressive force and her tendency, analyzing a minimal compressive force for gripper rolling.

So that the model can creates a truly and easier results analyze must realize in superior simulation interface with ability to cover the other effects which are can not simulate in program MSC.Working Model 2D.

3. KINEMATICS ANALYSE OF MICROMACHINE

In regard to the requirements which are defined in phase of design process kinematics analyse of in-pipe micromachine is make.

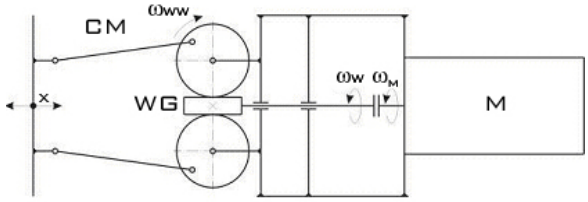

Fig.8 Kinematics scheme of in-pipe micromachine prototype

Kinematics scheme (Fig.8) includes actuator – micromotor (M) whose motion defines by angular velocity ω_M is through concentric transmission transmitted to worm of worm gearing (WG) (angular velocity ω_W). Front block of micromachine movement specific by parameter x is initialized through wheel of worm gearing (angular velocity ω_{WW}) by crank mechanism (CM). [5]

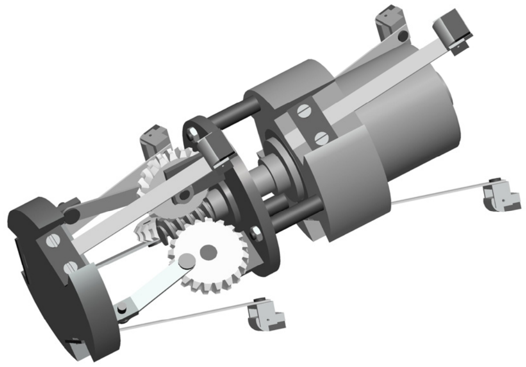

Fig.9 Simulation model of the in-pipe micromachine

Kinematics analyse of simulation model (Fig.9) created in Pro/ENGINEER was realized in Pro/MECHANICA. Results of micromachine's kinematics analyse is shown on fig.10.

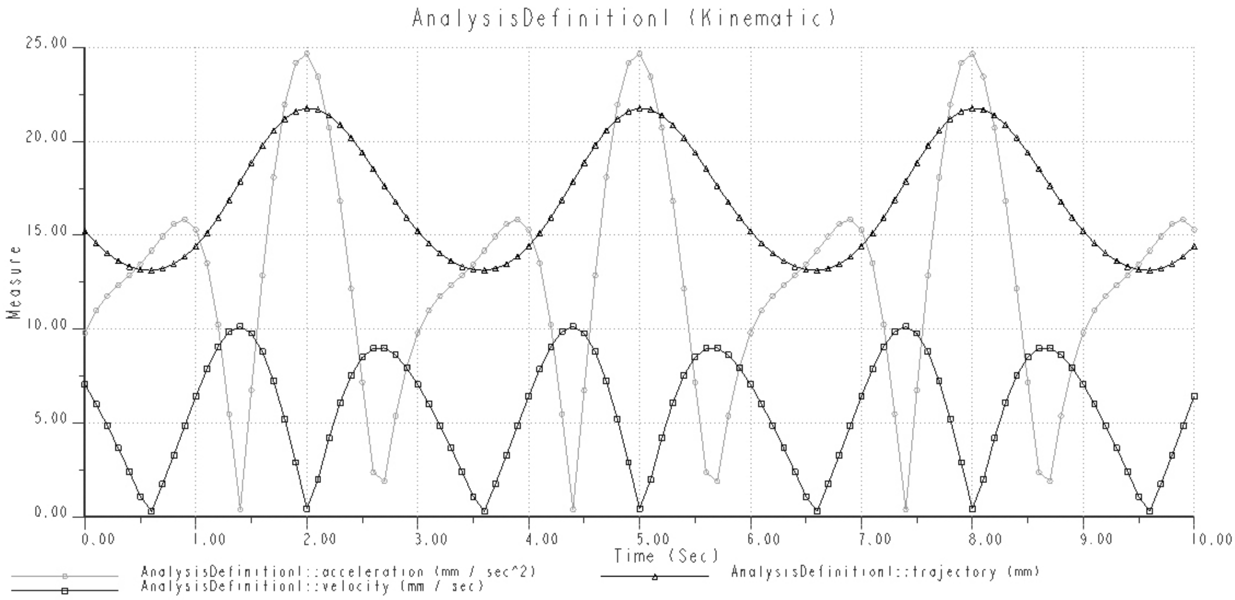

Fig.10 Results of micromachine's kinematics analyse

CONCLUSION

In article were described particular stages of design of in-pipe micromachine developed on the authors` department. Design is related to elaborate requests and parameterization, stages of concept design and prototype realization.

The result is the realized prototype. Analyses for smart bristles were realized for controlling the compressive force. In concepts was made a simply simulation of smart bristles movement and elaborated individual motion phases. On the real model of smart bristles was made the experiment for obtaining the adhesion coefficient.

In the next research we begin with the experimental verification of parameters for purposes of motion optimisation in limited area, study of analyses and synthesis of deflection and tolerances of precision mechanisms of in-pipe micromachine and the active control for compressive force of smart bristles.

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